EARTH SURFACE PROCESSES AND LANDFORMS, VOL. 21, 365–376 (1996)

WEATHERING BY WETTING AND DRYING: SOME EXPERIMENTAL RESULTS

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Received 17 November 1993
Accepted 8 February 1995

ABSTRACT

A series of experiments on sandstone and dolerite was undertaken in an attempt to better understand the wetting and drying weathering process. As rock samples are frequently subjected to wet–dry cycles within the simulation of other weathering mechanisms (e.g. freeze–thaw), three common methods of moisture application were used and the influences of these evaluated. It was found that the method of moisture application could affect the nature of the weathering products resulting from wetting and drying. It was also observed that there were changes in the internal properties of the rock (e.g. porosity/microporosity) and that these could influence the synergistic operation of other weathering processes. Although not all of the observations could be explained, it is apparent that wetting and drying has both a direct and an indirect effect on the weathering of rock that has not been taken into account in simulations. Greater cognizance needs to be given to the role of this process both in the field and in laboratory simulations.

KEY WORDS weathering; wetting and drying; simulations; sandstone; dolerite

INTRODUCTION

Temporal and spatial variability of rock moisture in cold regions are recognized as major factors affecting the nature and extent of rock weathering, (Hall, 1986, 1988a, 1991, 1992; Thorn, 1988, 1992). In addition to exerting a direct control on mechanical and chemical weathering processes, the fluctuations in rock moisture can themselves cause weathering (Pissart and Lautridou, 1984), so-called 'wetting and drying'. The process of wetting and drying is not well understood (Nepper-Christensen, 1965; Ollier, 1984; Hall, 1988b) but is recognized as affecting a whole range of rocks including those that do not have a clay component (Felix, 1983). A number of studies, on a variety of rock types, have suggested that moisture fluctuations cause weathering as a result of the rock expanding during take up of water and its inability to return to the original dimensions upon losing moisture (Nishioka and Harada, 1958; Nepper-Christensen, 1965; Venter, 1981; Felix, 1983; Pissart and Lautridou, 1984; Hames *et al.*, 1987). In addition, it has been shown that high moisture contents diminish rock strength (Brock, 1979; Dube and Singh, 1972) and that, through time, wetting and drying cycles can decrease the bonding strength of the component minerals such that, ultimately, there is a decrease in overall rock strength and possibly even failure (Pissart and Lautridou, 1984; Hall, 1988b). Furthermore, recent studies by Hall (1991, 1992) have suggested that fluctuations in moisture content, without the rock ever drying fully, result in wetting and drying taking place in a zone below the surface, where the effects may not be immediately apparent. This, in turn, can lead to rock failure that has previously been ascribed to other processes (e.g. freeze–thaw), or it can operate synergistically with other weathering processes, both facilitating their operation and abetting their overall effect. Recent studies by Haneef *et al.* (1993a, b) have reported on the applied aspects of wetting and drying interaction with pollutant acids and gases plus the significance of different rock associations. Finally, although it may be that wetting and drying is a relatively slow process, nevertheless the number of wet–dry repetitions in many areas,

CCC 0197-9337/96/040365-12

even polar areas, can be very high and may far exceed the number of 'effective' freeze–thaw cycles (Hall, 1992).

Although laboratory studies have attempted to elucidate the processes involved in wetting and drying, little information is available regarding actual rates of breakdown. These data are, however, very important for two reasons. First, information is needed regarding the rate of weathering by wetting and drying in its own right together with an understanding of what the nature of that rate is (i.e. linear, positively or negatively exponential, etc.). Second, the information is of paramount importance for assessing the true effect of other processes, such as freeze–thaw. Such processes are dependent upon the presence of moisture for their operation, and clearly moisture content varies through time or as a function or experimental procedures in laboratory experiments, so it is necessary to understand the effects of these moisture fluctuations if the role and rate of the process under study are to be ascertained. This second point is particularly important with respect to laboratory studies when frequently the aim is to investigate a single mechanism by attempting to filter out all other effects.

For cold regions, freeze–thaw is frequently cited as the major operative mechanism and large numbers of laboratory experiments have been undertaken in an attempt to ascertain either the mechanism involved or the rate of breakdown. Common to almost all of these experiments has been the non-natural apportionment of moisture. In other words, in the absence of field data on rock moisture content (McGreevy and Whalley, 1985) the rocks have been placed in trays where they were fully covered by water, partially covered or simply wetted (i.e. by spraying or having a limited amount of water poured over them). The rocks are then subjected to freeze–thaw cycles of various kinds with frequent drying events for reweighing, etc. Clearly, the rocks are also being subjected to wetting and drying, the effects of which are not known either in terms of process or rate of breakdown.

In this study, a series of experiments was undertaken in an attempt to elucidate the effects due to wetting and drying resulting from the apportionment of water to rock samples in the manner used in many freeze–thaw and/or salt weathering laboratory studies. In addition to indicating the weathering effects with respect to laboratory procedures, the resulting data also have applicability to field situations in which the manner of rock wetting is analogous to that used in the laboratory (see below).

EXPERIMENTAL PROCEDURE

Sandstone and dolerite samples used in the experiments were from areas where frequent moisture changes to the rocks were observed to be operative (sandstone from Drakensberg Mountains, South Africa; dolerite from Livingston Island, South Shetland Islands, Antarctica). Three procedures, common to many frost and salt weathering experiments (see McGreevy and Whalley, 1985), were utilized for providing moisture to the rock specimens: the covering of the rock sample by deionized water, half-covering the sample with water, and spraying the sample with a fixed amount of water (in this instance 50 ml). For each of these moisture allocation procedures, three samples of each rock type were used; all samples were roughly oblong with dimensions of approximately 8 × 4 × 3 cm. The samples were thus reasonably comparable with respect to size and shape within and between rock types. Prior to beginning the experiment, all the samples were saturated by immersion in water until a stable mass was reached; it took two days to obtain this saturated mass for the dolerite and one day for the sandstones. Following saturation, the samples were dried for 48 h at 105°C and weighed again. Knowing the saturated and the dry mass of the samples it was possible to monitor changes in both mass and percentage saturation throughout the experiment. The covered and half-covered samples were weighed in the morning, put in their trays of water and then left for 3 h. They were then removed, weighed and left to dry at room temperature (*c.* 19°C) until the following morning, when the procedure was repeated The sample to be sprayed with water was first weighed, then sprayed with 50 ml of water and left for 10 min in a closed glass container prior to being weighed again. The wetted sample was left in the closed glass container for 3 h and then subjected to the same procedure as the other two samples, described above. The 3 h wetting period was used partly for logistical reasons but is was also felt that a 3 h wetting followed by a 21 h drying is possibly realistic with respect to many field situations, e.g. as could be produced by the wetting of rocks at the margins of meltstreams during peak flow, the melting of snow that settled on

warmed rock and then evaporated, or short rain events followed by sun or wind that caused moisture loss. At weekends the sample was left to dry for three days (Friday to Sunday) and so a lower mass is seen on the graphs after every four day (Monday to Thursday) period.

RESULTS AND DISCUSSION

The results for each of the three moisture regimes can be considered under four main headings:

(1) material weathered free from the rock as expressed by changes in sample dry mass;
(2) weathering of the rock affecting the internal structure as shown by changes in water holding ability;
(3) the influence of variation in experimental procedure duration on the degree of saturation; and
(4) the significance of the findings with respect to weathering rates and processes in both the field and the laboratory.

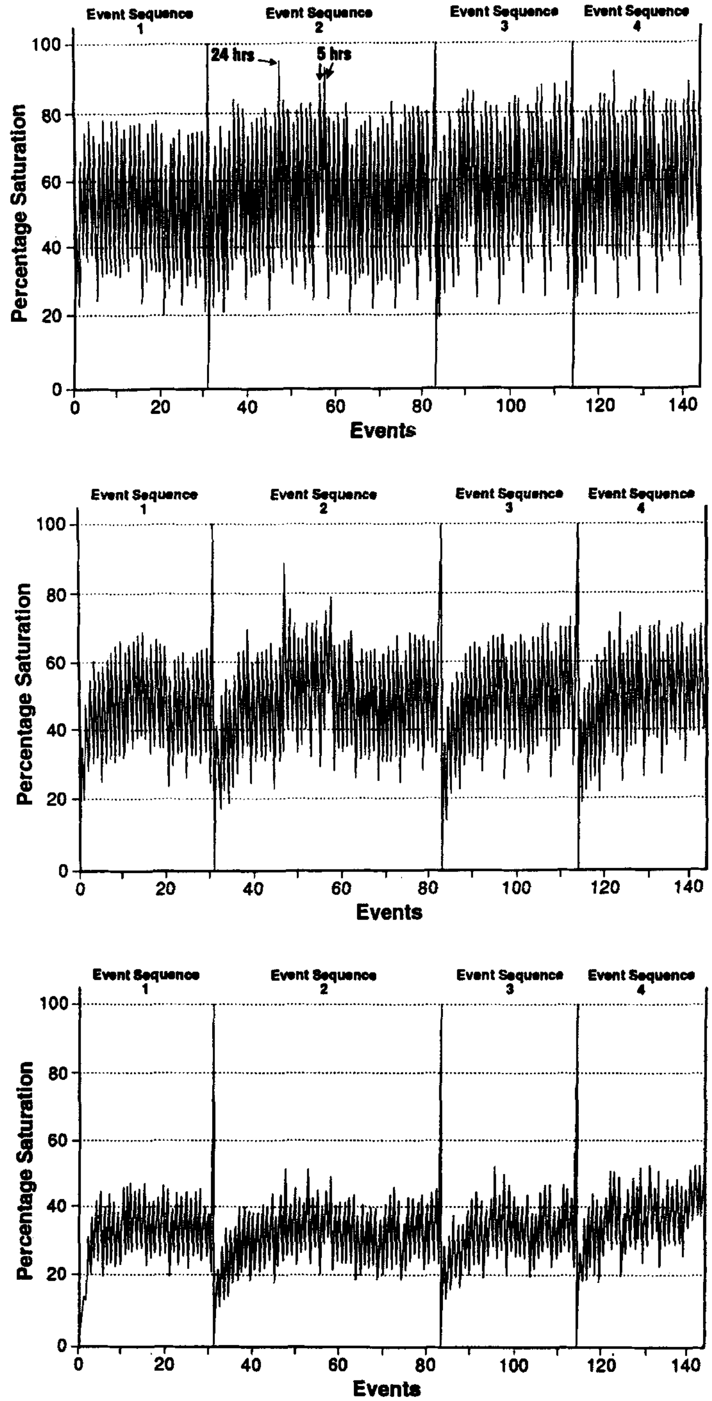
Responses with respect to percentage saturation between the three samples in each of the moisture allocation procedures were very similar indeed. Correlation values within each moisture set were all greater than $r = +0{\cdot}9$; values ranged between a low of $r = +0{\cdot}9088$ (samples 1 and 2 of Elliot sandstone, totally covered) and a high of $r = +0{\cdot}98893$ (samples 1 and 3 of dolerite, totally covered). Thus, the data presented below are for sample 1 in each of the three rock types in each of the moisture allocation procedures as, with such consistently high correlation values, these can be considered representative of the sample group in each instance.

No 'control' experiment was run for three main reasons. First, to leave a sample of each rock type in water for the duration of the experiment would have been of dubious significance, with any changes reflecting, primarily, chemical weathering effects of long-term immersion, a factor not being considered in this experiment. Second, and perhaps more importantly, leaving a sample in water would have replicated only one of the sample wetting procedures; there would have been no relationship to the sprayed sample. Third, the effects of long-term saturation had already been considered by Felix (1983). His findings were mainly that it enabled the separation between '..water-sensitive facies, generally prone to rapid weathering, from partially, to non-sensitive ones' (Felix, 1983, p. 310). What had not hitherto been done was to monitor the changes to rock moisture content and from that to deduce the changes to rock properties and hence the weathering effects. Thus, in effect, the experiments undertaken here go someway towards answering the questions raised by Nepper-Christensen (1965) and Felix (1983) regarding the effects of, and changes to, the pore size distribution and their effects, direct and indirect, upon mechanical weathering.

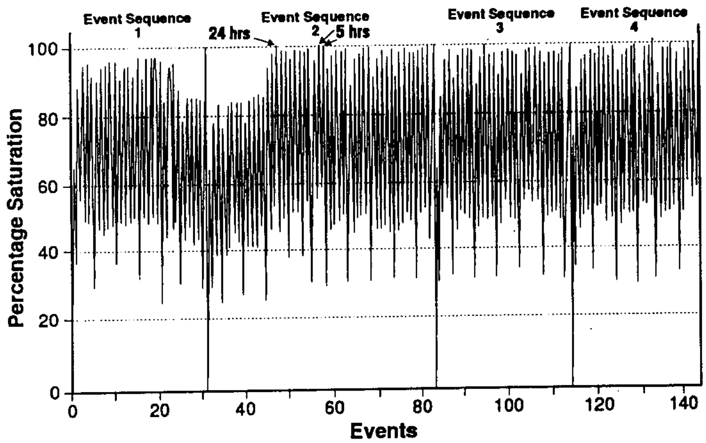
In the presentation of the results (Figure 1) the terms 'events', 'event sequence' and 'percentage saturation' are used. 'Event' simply refers to daily measurements, in other words the daily weighing, wetting and weighing cycles, i.e. each wet–dry event. The event sequence is the series of events between times when the samples were dried and saturated again in order to monitor changes in water-holding capacity and to enable the mass loss to be determined. In determining saturation, the sample was again placed in water and allowed to stand until a stable mass was obtained; the time taken to achieve this was noted as it was found to take longer than the one or two days needed at the start of the experiment. Percentage saturation is the amount of water that was held compared to how much the sample could hold, presented as a percentage. Data were corrected throughout as a function of mass loss (i.e. if mass were lost then the original, experiment start values would no longer be valid) and as the water-holding capacity of the rock changed through time. The percentage saturation values are thus meaningful as they were corrected for changes in sample properties and mass during the experiment rather than the more normal procedure of obtaining only start and end values, which does not allow for this on-going correction to be undertaken.

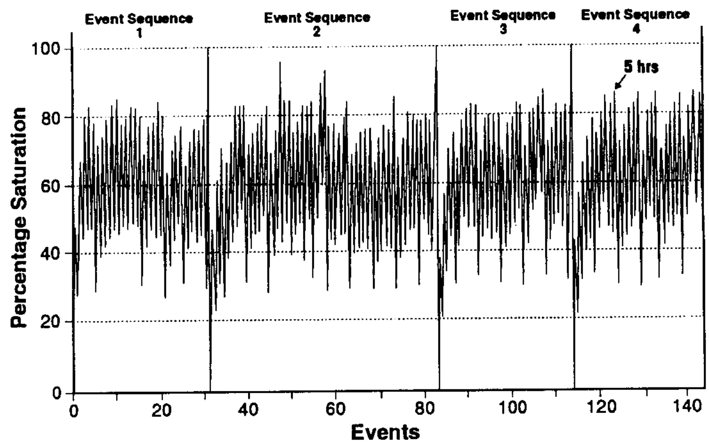
Details of mass loss

Details of the mass lost for the two sandstones and the dolerite after 140 cycles are shown in Table I. The fact that the covered and half-covered samples with the exception of the Elliot sample, responded in such a similar manner may reflect the availability of water rather than the degree of cover. In other words, although only half submerged, the rock was able, via capillary forces, to continue to take up water and thus responded in a similar manner to the totally covered sample. Even in the case of the Elliot sample, if the large (20·5 g)



Event Sequence 1
Event Sequence 2
Event Sequence 3
Event Sequence 4
24 hrs
5 hrs
Percentage Saturation
0
20
40
60
80
100
0
20
40
60
80
100
120
140
Events
Event Sequence 1
Event Sequence 2
Event Sequence 3
Event Sequence 4
Percentage Saturation
Events
Event Sequence 1
Event Sequence 2
Event Sequence 3
Event Sequence 4
Percentage Saturation
Events


Event Sequence 1
24 hrs
Event Sequence 2
5 hrs
Event Sequence 3
Event Sequence 4
Percentage Saturation
Events


Event Sequence 1
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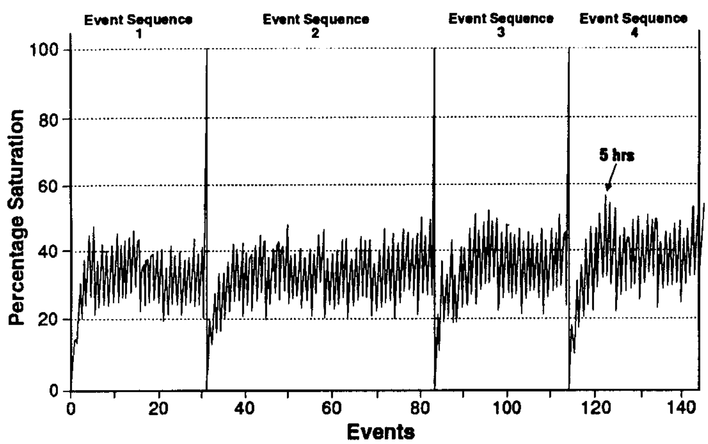
Event Sequence 1
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5 hrs
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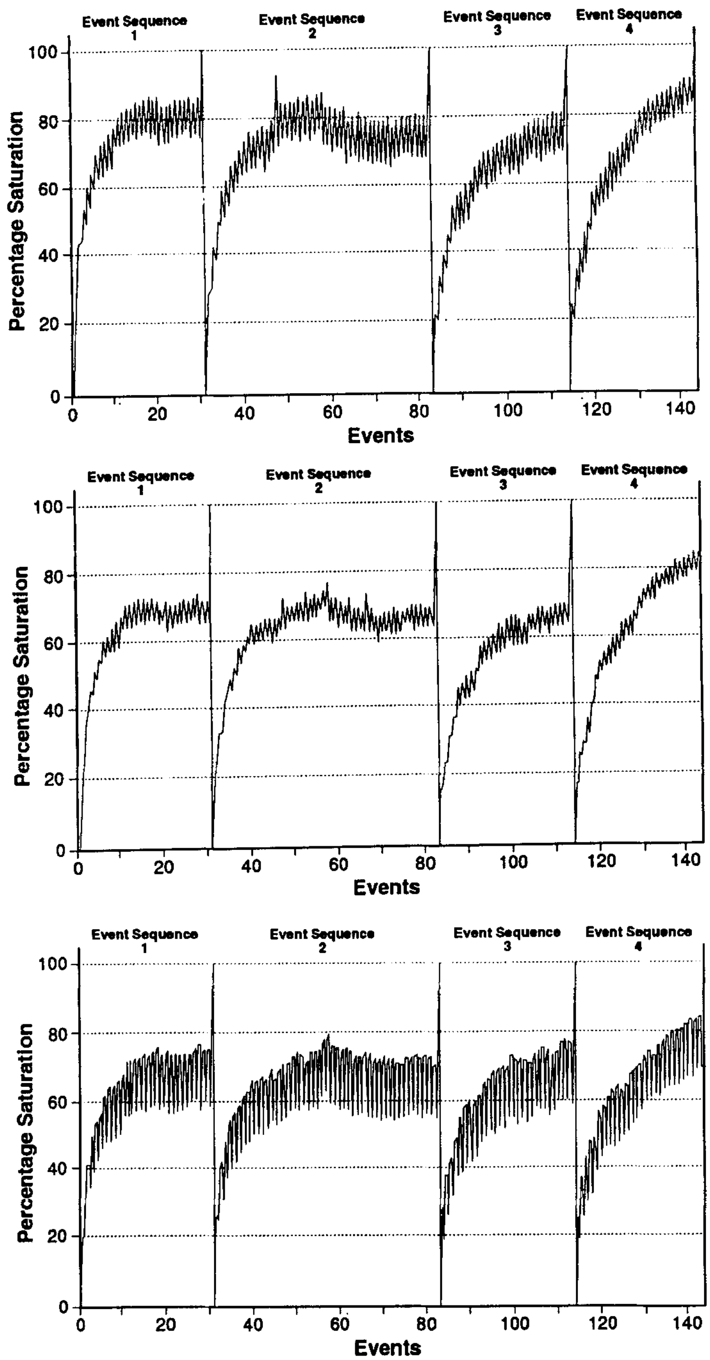

Figure 1. Graphs to show percentage saturation of the three rock types (Clarens sandstone, Elliot sandstone and dolerite) for the three methods of moisture application (covered, half-covered and sprayed): (1a) covered Clarens sst; (1b) half-covered Clarens sst; (1c) sprayed Clarens sst; (2a) covered Elliot sst; (2b) half-covered Elliot sst; (2c) sprayed Elliot sst; (3a) covered dolerite; (3b) half-covered dolerite; (3c) sprayed dolerite

Table 1. Percentage of mass lost after 140 cycles for the three rock types subject to the three modes of moisture application

	Covered	Half-covered	Sprayed
Clarens SST	0·26	0·26	0·11
Elliot SST	4·7*	0·47	0·14
Dolerite	0·47	0·45	0·32

* Pieces > 0·5 g lost from the covered Elliot sst = 0·7 g after event 14, 20·5 g after event 24 and 7·5 g after event 44

piece weathered free is ignored, it would appear that the mass loss for both the totally covered and half-covered samples is about the same. However, both the covered and half-covered samples show a much greater mass loss than those samples that were only sprayed with water. Surprisingly, it was the dolerite from the South Shetlands that showed the greatest percentage mass loss for the sprayed samples as, subjectively, it was thought the sandstones might be more prone to breakdown. Furthermore, all the samples (both sandstones and dolerite) lost small 'splinters' of rock from the covered and half-covered samples but no obvious 'splinters' occurred from the sprayed samples, which only experienced granular disintegration.

The 20·5 g piece of rock that weathered free from one of the covered Elliot sandstone samples was the largest piece produced during these experiments. However, the Elliot sandstone consistently lost larger pieces than the other lithologies with, for the sample identified here, a piece of 0·7 g lost after event 14, the 20·5 g piece after event 24 and a piece of 7·5 g after event 44 (Table I). Thus, it may well be that the Elliot sandstone is particularly prone to this form of weathering. It is also worth noting that the pieces were lost from the covered Elliot sandstone sample near the start of the experiment and so if percentage of weight of sample remaining compared to original weight is plotted against the number of cycles on the x-axis, this produces the reversed 'S'-shaped graph discussed by Yatsu (1988, p. 115), said to be indicative of a slow rate of breakdown.

Although it is generally perceived that mainly shales and tuffs, or rocks with a high clay content, experience the expansion–contraction of wetting and drying, several studies have shown that a whole range of other rocks can also be affected (e.g. see Nishioka and Harada (1958) for details regarding sandstones, schists, limestones, marbles, cherts, granites, basalts, talc, obsidian and a number of other rock types, and Nepper-Christensen (1965) for basalt and flint). In fact, Nepper-Christensen (1965, p. 554) states 'Many, if not all, rocks are sensitive to variations in the relative humidity of the surrounding atmosphere since they shrink and swell as they give off or absorb moisture', and adds that clay minerals are but one factor influencing the process, '...mineral composition and pore structure are probably important factors...' (p. 555). This conclusion is reiterated by Felix (1983, 1984, 1987) based on studies of sandstone, '...the swelling is, therefore, strongly influenced by the pore size distribution...water sensitivity appears...as a complex combination of mineralogical (clay minerals) and structural factors, yet to be defined' (Felix, 1983, p. 310); Felix also noted (p. 309) that several studies shown '... the strong effect of water sorption on the expansive properties of rocks not containing clay minerals'. Thus, contrary to many general perceptions, wetting and drying can have an expansion–contraction effect upon a whole range of rocks including those that have no clay minerals. The actual cracking of the rock is thought to be most active during submergence rather than during desiccation (Yatsu, 1988), the cause being related to the swelling or expansion strains that are developed in the rock when it takes up moisture (Hames *et al*, 1987; Pissart and Lautridou, 1984). This, then, would clearly help explain why the submerged and half-covered samples showed significantly greater degrees of breakdown than did the sprayed samples. What is not entirely clear is why, with the exception of the Elliot sandstone, the fully submerged samples did not exhibit a greater mass loss than the half-covered samples.

It is the nature of the 'materials contained in rocks, tensile strength and the structure of the rocks, and the pore size distribution that are all important' in wetting and drying (Yatsu, 1988, p. 115). Whatever the cause of the difference in effects between the Elliot and Clarens sandstones, and between the sandstones and the

dolerite, there are clear implications for laboratory simulations. By covering, or even half covering, rock samples with water and then subjecting them to freeze–thaw cycles during which water loss and replacement occurs within the experiment, then a component of weathering due to wetting and drying affects the final result. The role of wetting and drying has two elements. First, there are the direct effects in terms of mass loss due to the wetting and drying process itself, and in some rock types this could be significant. Second, it operates synergistically by generating large cracks (Yatsu, 1988) that are then available to be exploited by the frost processes. Without the generation of these cracks the efficiency of freeze–thaw would be reduced. In other words, the wetting and drying effects abet the freeze–thaw mechanism.

With respect to salt weathering, the same principles apply. However, the rate of breakdown due to wetting and drying with a saline solution can be slower than with fresh water for a number of reasons (Yatsu, 1988): there is less water penetration due to the large surface tension and higher viscosity of salt water; desiccation is slowed as a result of surface coating by salts and of the attractive forces between clay grains being intensified thereby strengthening the rock. Nevertheless, there is still a wetting and drying effect to be taken into account. The same is the case for studies of thermal stress and fatigue such as those of Griggs (1936), Blackwelder (1933) and Birot (1960), all of whom concluded that the addition (by immersion) of water to the rock samples greatly accentuated weathering rates. As more recent studies (e.g. Yong and Wang, 1980) have shown, microcracking of granite can occur with temperatures of 72°C or greater, so the combination of this with the effects of wetting and drying (caused by immersion in water followed by heating) could be expected to exacerbate the rate of breakdown.

Effects upon the internal structure of the rock

The second topic, namely changes to the internal structure of the rock as expressed by changes in rock properties, complements the above discussion, particularly with respect to the effects of wetting and drying abetting other processes. Here, it is the change in the internal structure of the rock, as indicated by changes in the water-holding property of the rock (i.e. the percentage saturation), that is considered. Figure 1 indicates that for the dolerite there is an increase in percentage saturation with time for all three sample procedures but with the overall percentage saturation being: covered > half – covered > sprayed. There must be an increase in the size of pores/microfissures and/or an increase in their numbers within the rock to explain this increased percentage saturation. Five other interesting elements can be seen from the figures: (1) the diurnal fluctuations on the rising (wetting) limbs; (2) the drop in percentage saturation later in the event sequences; (3) the unusual 'low' level in the third event sequence; (4) the sprayed samples show a greater diurnal variation in percentage saturation; (5) an increase in overall saturation.

In all three sample procedures it is very clear that, for the dolerite, after each drying event the rising limb of the graph becomes less steep and, at the same time, shows the effects of diurnal changes earlier and with greater frequency. For reasons not yet understood, there was a continuous gain of moisture, with no diurnal loss, on the rising limb of event sequence 1 (i.e. cycles 1–32 through to saturation and total drying). In event sequence 2, the rising limb again indicated a continual mass gain but the effects of diurnal variations began much earlier, whilst in event sequences 3 and 4 the diurnal responses became apparent earlier and occurred with ever-increasing frequency. Quite why these changes should occur is unclear, but the fact that the rising limbs are seen to become more gentle suggests that it is taking longer for the dolerite to absorb water. This may partly reflect the effects of the increasing diurnal variability (i.e. by events 3 and 4 there is a greater diurnal change than was found in event 1). However, the dolerite, which took only two days to fully (i.e. 100 per cent) saturate at the experiment start, took five days to fully saturate after event 4; thus other changes must also have been occurring. One explanation is that the pores near the rock surface are getting bigger and that concurrently there is an increase in the micropores and fissures inside the rock. Thus the gain and loss of water from the larger, surficial pores is the cause of the diurnal variability seen on the rising limbs, but the increase of micropores means it takes longer for the whole rock to saturate. Indeed, data regarding porosity and microporosity, as determined by the methodology of Cooke (1979), do show marked change for the dolerite, as has been argued above (Table II). However, no detail regarding the actual size of the 'micropores' is available and so, until these experiments can be repeated with detailed porosimetry at selected intervals during the experimental sequence, the suggestions must be given in generalized terms. Interestingly, the

Table II. Changes in porosity and microporosity for the dolerite after the three different modes of moisture application, compared with average initial values

	Porosity	Microporosity
Initial values	2·86	27·31
After spraying	3·64	85·38
After half immersion	5·0	95·29
After full immersion	4·98	96·59

sandstones did not show these changes and the time for total saturation (24 h) at experiment start was the same after event sequence 4.

It can be seen from the graphs (Figure 1) of both sandstones and the dolerite that the rising limbs reach a 'plateau'. However, in event sequences 1 and in particular, 2 there can be seen to be a *decrease* after the plateau high is reached. Again, quite why this should occur is not certain but it may reflect a change in porosity/microfractures such that it is easier for more water to be lost (i.e. the voids have been enlarged). If this is the case then it might help explain why there is a general rise in percentage saturation from event sequence 1 through to event sequence 4, e.g. for the dolerite from *c.* 86 per cent saturation in sequence 1 to *c.* 93 per cent saturation in sequence 4 for the fully covered sample; from *c.* 73 per cent in sequence 1 to 84 per cent in sequence 4 for the half-covered samples; from $\leq$ *c.* 77 per cent in sequence 1 to *c.* 85 per cent in sequence 4 for the sprayed sample. Thus, there does seem to be an increase in water-holding capacity, as shown by the general increase in percentage saturation, and this must reflect an increase in porosity/microfissure size and/or numbers to accommodate this. The same general changes are evident in the two sandstones but the change is most evident in the sprayed samples.

Event sequences 1 to 4 would show a consistent linear increase in percentage saturation, as discussed above, were it not for event sequence 3. Here, as the graphs clearly show, there was a *decrease* in percentage saturation for all the sample procedures. Again, the cause is not clear and the only common factor is that event sequence 2 was particularly long (49 rather than 32 events). However, the longer event sequence exhibited a post-plateau decrease in percentage saturation (as noted above) ending, for the dolerite, at *c.* 80 per cent saturated, which is the plateau attained by event sequence 3; post-event 2 highs were greater in the two sandstones although they did not achieve the levels of event 2. This, then, begs the question as to why event sequence 4 should show such a marked increase in percentage saturation? Clearly the effects of wetting and drying are anything but simple!

Finally, the data for the dolerite show not only the degree of saturation which the samples could attain under the experimental conditions in use (which may have parallels with some field situations), but also the diurnal variability as a function of the daily wetting and drying events. Even here some unexpected results were obtained. Not surprisingly, perhaps, the daily range (i.e. the difference between the 'wet' and 'dry' levels) for the covered sample was greater than that for the half-covered sample. However, the daily range for the sprayed sample was almost twice as great as that of the water-covered sample, with a daily range of nearly 20 per cent. Why such a sharp contrast? One possibility, which explains both the high daily range and the generally lower overall degree of saturation of the sprayed sample, is that, owing to limited water being available and the short period of application, it was not possible to fill the smaller pores and/or fissures. Thus, on the sprayed sample only the large voids took in water and these would more readily and rapidly lose it during the drying period. In the more saturated samples, once the smaller pores were filled (as shown by the gradual overall increase in percentage saturation) they would not lose moisture so rapidly. Also, the overall degree of saturation was higher in the samples located in trays of water and, recognizing that the water must have penetrated substantially to produce a > 80 per cent saturated sample, it was less easy for water deep inside the rock to migrate to the margins within the time frame of the drying periods used here. Daily differences between the wet and dry states were much greater in the sandstones compared to the dolerite, as might be expected owing to their greater porosity.

The influence of variation in experimental procedure

With respect to experimental procedure, it is found that this can have a marked effect. For all samples, the relative degree of saturation was: covered > half – covered > sprayed. However, the differences between the applications were very small for the dolerite (as discussed above, Figure 1), greater for the Clarens sandstone and greatest for the Elliot sandstone, where the sprayed level of saturation was approximately 50 per cent of that for the sample fully immersed in water. Further, the Elliot and the Clarence sandstones both attained similar levels of saturation by spraying, but the Elliot was marginally higher than the Clarence in the half-covered procedure (80 per cent vs. 60 per cent) and also in the fully covered sample (> 90 per cent vs. 80 per cent). This, then, implies that for the Elliot sandstone, an almost 100 per cent saturated condition is attained with only 3 h submersion in water. Thus, the properties of the individual rocks play a crucial role in determining the effects of the various means of applying moisture. This implies that rocks should be tested with respect to this as an integral part of any test sequence for frost, salt or other form of water-based weathering.

The duration of wetting and/or drying, not surprisingly, was shown to exert an influence on the degree of saturation. However, as obvious as this may be, it is a factor *not* quantified in frost of salt experiments. For example, the Elliot sandstone, if given water for 24 h shows little or no difference from the level of saturation attained after only 3 or 5 h. For the Clarens sandstone, a 5 h wetting period produces a level of saturation about 10 per cent lower than does a 24 h, wetting; for the dolerite there is an 11 per cent difference (86 per cent vs. 97 per cent). Thus, even a relatively short (i.e. 3 or 5 h) period of wetting will attain high levels of saturation and this, in turn, may have important ramifications for freeze–thaw experiments. This is particularly so as saturation levels of 80 per cent or greater imply that, as a result of the moisture gradient within the rock, a substantial portion of the outer part of the rock must be at, or very close to, 100 per cent saturation; such conditions are required by many of the hypotheses and models of frost action.

Significance of the findings with respect to weathering

Although the implications of some of the findings reported above are uncertain, it is clear that wetting and drying of rock samples during laboratory experiments can have an influence on the nature, degree and rate of breakdown. That there is debris loss as a result of *just* wetting and drying implies that this effect must influence the results of freeze–thaw or salt weathering experiments. Furthermore, Letavernier (1984) and Letavernier and Ozouf (1987) have suggested that any index of frost susceptibility should not be based upon the amount of the original rock sample left after testing but rather on a 'coefficient of comminution' (coefficient d'amenuisement) based on the particle size distribution of the resulting fragments between 0·5 and 2·5 cm. This is certainly important for it recognizes the fact that particles detached from the original block are themselves subject to breakdown. However, from this present experiment it would seem that the manner of moisture application helps determine the character of the resulting debris produced by wetting and drying (covered and half-covered samples give 'splinters', sprayed samples give granules) and this could have an influence on the particle size distribution. Furthermore, the debris would themselves experience saturation–drying cycles that would result in breakdown additional to any frost effects and so influence the resulting granulometric curve.

Thus it would seem that in addition to the laboratory experiment of frost or salt weathering there should be concurrent assessment of the weathering due to wetting and drying effects of moisture application. The 'norm' in most laboratory experiments of frost or salt weathering has been to use samples in distilled water as a control (and even this has varied greatly from experiment to experiment (McGreevy and Whalley, 1985)). However, this approach has only been used to see what degree of weathering (i.e. mass loss) would have taken place as a result of the moisture conditions in the absence of the salt or frost effects. What these controls have not done (in the instance where they have been used) is to tell the effects, in terms of changes to pore size distribution and water-holding capacity that, as a result of the wetting and drying, have had an effect upon the frost or salt weathering process; rather, they have simply documented the amount of weathering (as identified by mass loss) that took place. The data presented here show that the wetting and drying alone can influence pore and moisture conditions as well as effecting weathering in its own right. Thus, the results of such a concurrent experiment would not only indicate the amount and character of debris that

could be produced but would also provide information of changes in rock properties that might enhance or inhibit the effects of frost or salt weathering. With so little known regarding the role and influence of wetting and drying, combined with the variability, both within and between lithologies, of rock properties, there is a need for more information from laboratory experiments.

With respect to the field, the information presented here indicates that greater cognizance should be accorded to the role of wetting and drying as both a weathering mechanism in its own right and as one that acts synergistically with other processes. Apart from obvious locations such as tidal areas and the margins of lakes or rivers, where wetting and drying can occur frequently, there are situations, for example in association with snowbanks, where this process may be common. Bedrock and debris near ablating snowbanks may be subject to frequent wetting and drying cycles as water is produced during warm, dry periods and then evaporates during the cooler, frequently windy, periods. Such a concept could help explain the breakdown of material in association with a snowpatch (i.e. in nivation or cryoplanation).

In other areas, as has been argued for the South Shetland Islands by Hall (1993), rain can occur frequently during the summer. This results in wetting and drying of bedrock taking place during a time when other mechanical processes are not active. As a consequence, rock breakdown continues during this summer period and the rock properties are altered such that winter processes (e.g. freeze–thaw) are more effective. As a result of what can, in some locations, be large numbers of wetting and drying events (Hall 1993), this form of weathering could be more effective than the more usually cited freeze–thaw.

CONCLUSIONS

It would seem that the process of wetting and drying is even more complicated than was hitherto thought. Whilst a number of the findings reported here are unclear and the explanations of others speculative, it is certain that wetting and drying operates as a weathering mechanism in its own right and that the nature of the weathered material is influenced by the manner of wetting. Furthermore, the process of wetting and drying has an effect upon the internal characteristics of the rock and this, in turn, can influence the nature and degree of other weathering processes operating synergistically with wetting and drying. The results presented here indicate three important future avenues of research. First, investigation of wetting and drying as a process in its own right and the need to understand exactly how it operates. Second, field data collection of the frequency and degree of saturation of rocks in different environments. Third, and perhaps of major importance, the testing of rocks for wetting and drying effects within the context of freeze–thaw, salt and water-based chemical weathering experiments to ascertain the role that this process plays.

ACKNOWLEDGEMENTS

We would like to thank the Foundation for Research and Development for funding the research, and Mrs Margeot for redrawing the graphs. The comments and suggestions of Albert Pissart, John Dixon, Jean-Pierre Lautridou, Jean-Claude Ozouf and Angelique Prick were much appreciated and greatly helped in trying to understand the results. Several referees made a number of useful comments and pointed out shortcomings in the original text.

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